# Attachment C

# Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases with AERMET ADJ_U* and AERMOD LOWWIND3 Options

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## Introduction

In a proposed rulemaking published in the July 29, 2015 Federal Register (80 FR 45340), the United States Environmental Protection Agency (EPA) released a revised version of AERMOD (15181), which replaces the previous version of AERMOD dated 14134. EPA proposed refinements to its preferred short-range model, AERMOD, involving low wind conditions. These refinements involve an adjustment to the computation of the friction velocity ("ADJ_U*") in the AERMET meteorological pre-processor and a higher minimum lateral lateral wind speed standard deviation, sigma-v ($\sigma_v$), as incorporated into the "LOWWIND3" option. The proposal indicates that "the LOWWIND3 BETA option increases the minimum value of sigma-v from 0.2 to 0.3 m/s, uses the FASTALL approach to replicate the centerline concentration accounting for horizontal meander, but utilizes an effective sigma-y and eliminates upwind dispersion".[1]

This document describes the evaluation of the combined ADJ_U* and LOWWIND3 options as recommended by EPA for incorporated as default options in AERMOD version 15181 on two previously evaluated tall-stack databases as described by Paine et al. (2015)[2]. Here we compare the model evaluation results of these new options relative to the various modeling options previously tested model options in AERMOD version 14134.

## Modeling Options and Databases for Testing

The meteorological data, emissions, and receptors used in this analysis were identical to Paine et al. (2015) analysis. Two AERMET/AERMOD model configurations were tested for the two field study databases.

- AERMET and AERMOD in default mode with version 15181.
- Low wind beta option for AERMET (ADJ_U*) and the LOWWIND3 option for AERMOD (LOWWIND3 automatically sets minimum $\sigma_v$ value to 0.3 m/sec) with version 15181.

The results were compared to the five AERMET/AERMOD model configurations previously tested in Paine et al. (2015) with version 13350.

- AERMET and AERMOD in default mode.

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[1] Addendum User's Guide for the AMS/EPA Regulatory Model – AERMOD
http://www.epa.gov/ttn/scram/models/aermod/aermod_userguide.zip

[2] Paine, R., Samani, O., Kaplan, M. Knipping, E., and Kumar, N. Evaluation of Low Wind Modeling Approaches for Two Tall-Stack Databases. Pending publications (as of August, 2015) in the Journal of Air & Waste Management Association.

- Low wind beta option for AERMET and default options for AERMOD (minimum $\sigma_v$ value of 0.2 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum $\sigma_v$ value of 0.3 m/sec).
- Low wind beta option for AERMET and the LOWWIND2 option for AERMOD (minimum $\sigma_v$ value of 0.5 m/sec).
- Low wind beta option for AERMET and AERMOD run in sub-hourly mode (SHARP).

All model applications used one wind level, a minimum wind speed of 0.5 m/sec, and also used hourly average meteorological data with the exception of SHARP applications.

The Mercer County, North Dakota and Gibson Generating Station, Indiana databases were selected for the low wind model evaluation due to the following attributes:

- They feature multiple years of hourly $SO_2$ monitoring at several sites.
- Emissions are dominated by tall stack sources that are available from continuous emission monitors.
- They include sub-hourly meteorological data so that the SHARP modeling approach could be tested as well.
- There is representative meteorological data from a single-level station typical of (or obtained from) airport-type data.

**Model Evaluation Results**

The model evaluation employed metrics that address two basic areas:

1) 1-hour $SO_2$ NAAQS Design Concentration averaged over the years modeled at each monitor.

An operational metric that is tied to the form of the 1-hour $SO_2$ NAAQS is the "design concentration" ($99^{th}$ percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for each modeled case and for each individual monitor for each database evaluated.

2) Quantile-Quantile Plots for each monitor.

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots, which are widely used in AERMOD evaluations. Q-Q plots are created by independently ranking (from largest to smallest) the predicted and the observed concentrations from a set of predictions initially paired in time and space. A robust model would have all points on the diagonal (45-degree) line.

**North Dakota Database Model Evaluation Procedures and Results**

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99$^{th}$ percentile averaged over four years at the five ambient monitoring locations. A regional background of 10 µg/m$^3$ was added to the AERMOD modeled predictions, as determined from a review of rural monitors unaffected by local sources.

The 1-hour $SO_2$ design concentrations and ratios of the modeled (including the background of 10 µg/m$^3$) to monitored design concentrations for the North Dakota evaluation database are summarized in Table 1 and graphically plotted in Figure 2. The results of the Paine et al. (2015) model evaluation analysis for the five options (version 13350) is shown here along with the results of the new evaluation with AERMOD version 15181.

The overall results indicate that the predicted-to-observed ratios are generally greater than 1.0 and AERMOD version 15181 still over-predicts even with use of the proposed ADJ_u* and the LOWWIND3 options. The low wind options show improvement relative to the default options at all monitors, especially the monitor in higher terrain (DGC #17).

As shown in Figure 1, and as expected the results for the new model with low wind options are very close to the AERMOD version 14134 model with ADJ_U* and LOWWIND2. The results of the two model versions with default options are also very close to each other.

The Q-Q plots of the ranked top fifty daily maximum 1-hour $SO_2$ concentrations for predictions and observations are shown in Figure 2 (a-e) for AERMOD version 15181 default and low wind options. For the convenience of the reader, a vertical dashed line is included in each Q-Q plot to indicate the observed design concentration. In general, the Q-Q plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for DGC #17).

**Gibson Generating Station Database Model Evaluation Procedures and Results**

AERMOD was run for the two version 15181 configurations described above to compute the 1-hour daily maximum 99$^{th}$ percentile averaged over three years at the four ambient monitors. A regional background of 18 $\mu g/m^3$ was added to the AERMOD modeled predictions.

The ratio of the modeled (including the background of 18 $\mu g/m^3$) to monitored concentrations is summarized in Table 2 and graphically plotted in Figure 3, and these ratios are generally greater than 1.0. The current version of AERMOD (version 15181) run in default mode showed no changes from the previous version's default results, still having over-predictions of about 10-50%. The proposed low wind options provided modest improvements in performance relative to the default options, while still showing an over-prediction tendency at each monitor.

The Q-Q plots of the ranked top fifty daily maximum 1-hour $SO_2$ concentrations for predictions and observations are shown in Figure 4 (a-d). As in the case of the North Dakota evaluation results, the Gibson plots indicate the following:

- For all of the monitors, to the left of the design concentration line, the ranked predictions are at or higher than observations.
- To the right of the design concentration line, some of the ranked modeled values are lower than the ranked observed levels (although this is not the case for Shrodt or Mt. Carmel for the low wind options).

**Conclusions**

The model evaluation results for the new version of AERMOD (version 15181) on the two databases showed that the proposed low wind options (ADJ_U* and LOWWIND3) perform better than the default options, while still overpredicting the design concentration at each monitor in both databases. Therefore, in conjunction with other evaluations that EPA reported at the 11$^{th}$ modeling conference on August 12, 2015, we recommend that EPA adopt the proposed low wind options default options, and allow their use in the interim for all modeling applications.

**Table 1: North Dakota Ratio of Monitored to Modeled Design Concentrations***

| Model Version | Test Case | Monitor | Observed | Predicted | Ratio |
|---|---|---|---|---|---|
| 13350 (previously reported results) | Default AERMET, Default AERMOD | DGC#12 | 91.52 | 109.96 | 1.20 |
| | | DGC#14 | 95.00 | 116.84 | 1.23 |
| | | DGC#16 | 79.58 | 119.94 | 1.51 |
| | | DGC#17 | 83.76 | 184.48 | 2.20 |
| | | Beulah | 93.37 | 119.23 | 1.28 |
| 15181 | Default AERMET, Default AERMOD | DGC#12 | 91.52 | 110.77 | 1.21 |
| | | DGC#14 | 95.00 | 117.51 | 1.24 |
| | | DGC#16 | 79.58 | 120.30 | 1.51 |
| | | DGC#17 | 83.76 | 184.49 | 2.20 |
| | | Beulah | 93.37 | 120.31 | 1.29 |
| 13350 (previously reported results) | Beta AERMET, Default AERMOD | DGC#12 | 91.52 | 109.96 | 1.20 |
| | | DGC#14 | 95.00 | 116.84 | 1.23 |
| | | DGC#16 | 79.58 | 119.94 | 1.51 |
| | | DGC#17 | 83.76 | 127.93 | 1.53 |
| | | Beulah | 93.37 | 119.23 | 1.28 |
| 13350 (previously reported results) | Beta AERMET, AERMOD with LOWWIND2 $\sigma_v$ = 0.3 m/sec | DGC#12 | 91.52 | 103.14 | 1.13 |
| | | DGC#14 | 95.00 | 110.17 | 1.16 |
| | | DGC#16 | 79.58 | 111.74 | 1.40 |
| | | DGC#17 | 83.76 | 108.69 | 1.30 |
| | | Beulah | 93.37 | 106.05 | 1.14 |
| 13350 (previously reported results) | Beta AERMET, AERMOD with LOWWIND2 $\sigma_v$ = 0.5 m/sec | DGC#12 | 91.52 | 95.86 | 1.05 |
| | | DGC#14 | 95.00 | 100.50 | 1.06 |
| | | DGC#16 | 79.58 | 106.65 | 1.34 |
| | | DGC#17 | 83.76 | 101.84 | 1.22 |
| | | Beulah | 93.37 | 92.32 | 0.99 |
| 15181 | Beta AERMET, AERMOD with LOWWIND3 | DGC#12 | 91.52 | 98.75 | 1.08 |
| | | DGC#14 | 95.00 | 112.09 | 1.18 |
| | | DGC#16 | 79.58 | 111.20 | 1.40 |
| | | DGC#17 | 83.76 | 108.76 | 1.30 |
| | | Beulah | 93.37 | 99.54 | 1.07 |
| 13350 (previously reported results) | SHARP | DGC#12 | 91.52 | 82.18 | 0.90 |
| | | DGC#14 | 95.00 | 84.24 | 0.89 |
| | | DGC#16 | 79.58 | 95.47 | 1.20 |
| | | DGC#17 | 83.76 | 88.60 | 1.06 |
| | | Beulah | 93.37 | 86.98 | 0.93 |

*Design Concentration: 99$^{th}$ percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

**Figure 1: North Dakota Ratio of Monitored to Modeled Design Concentration Values**

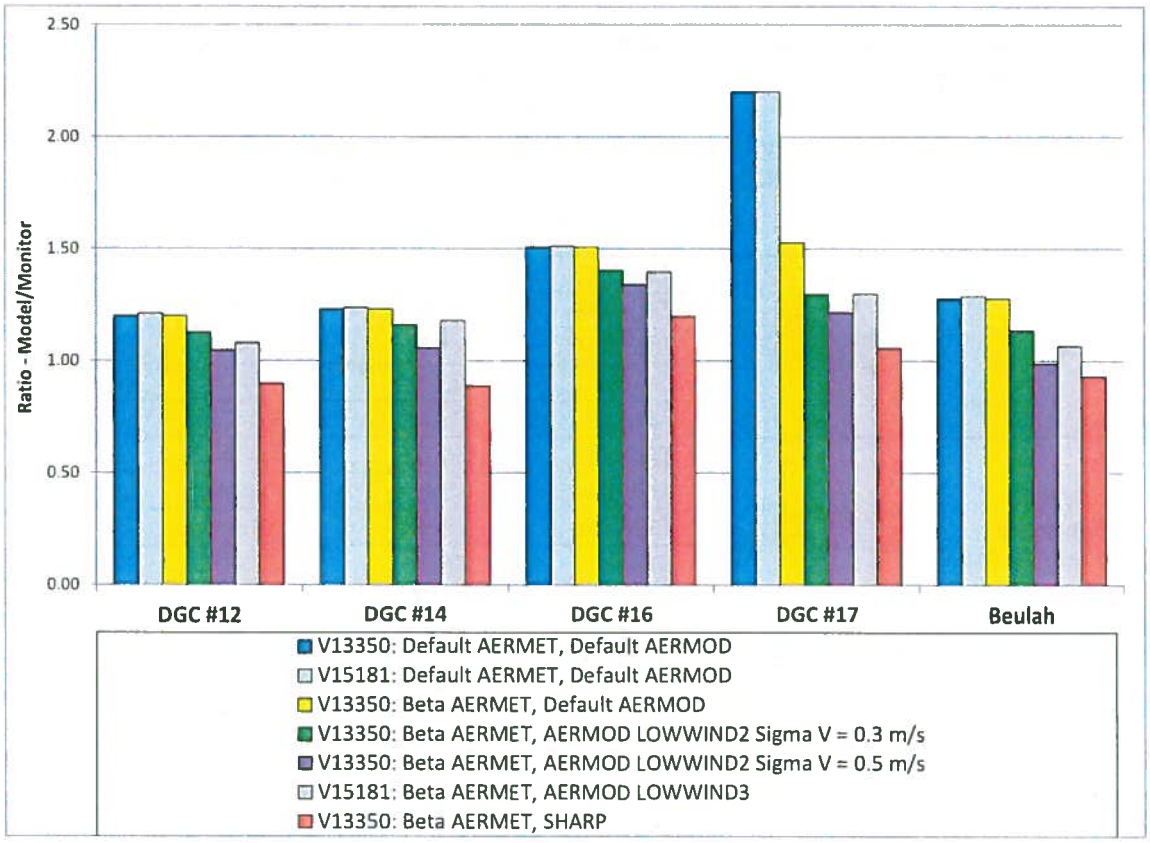
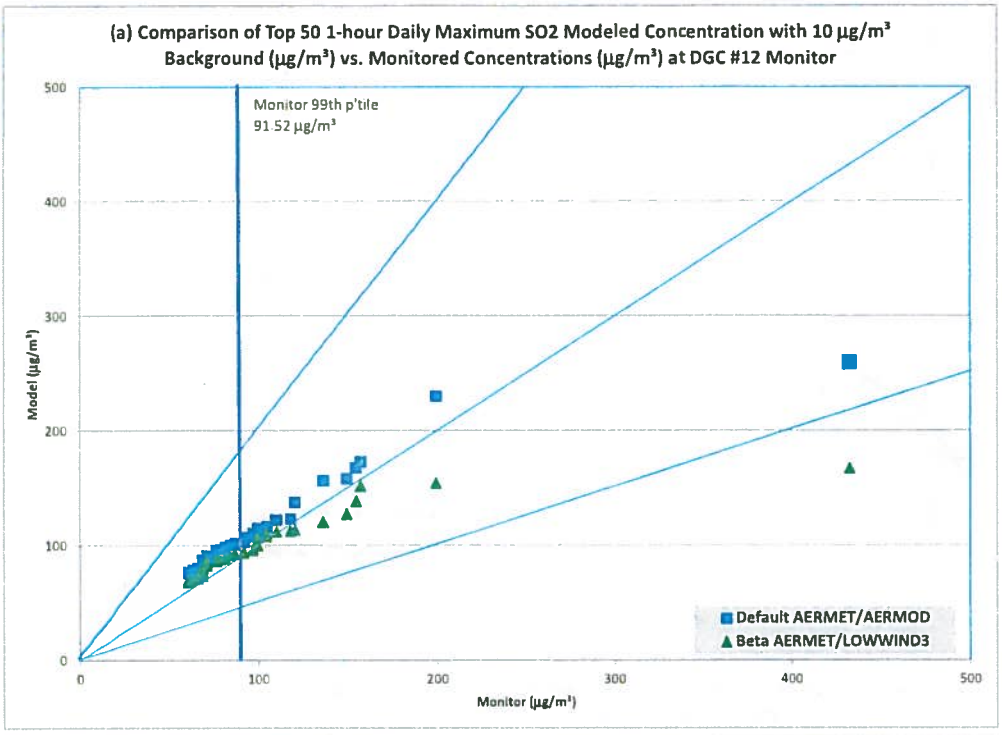
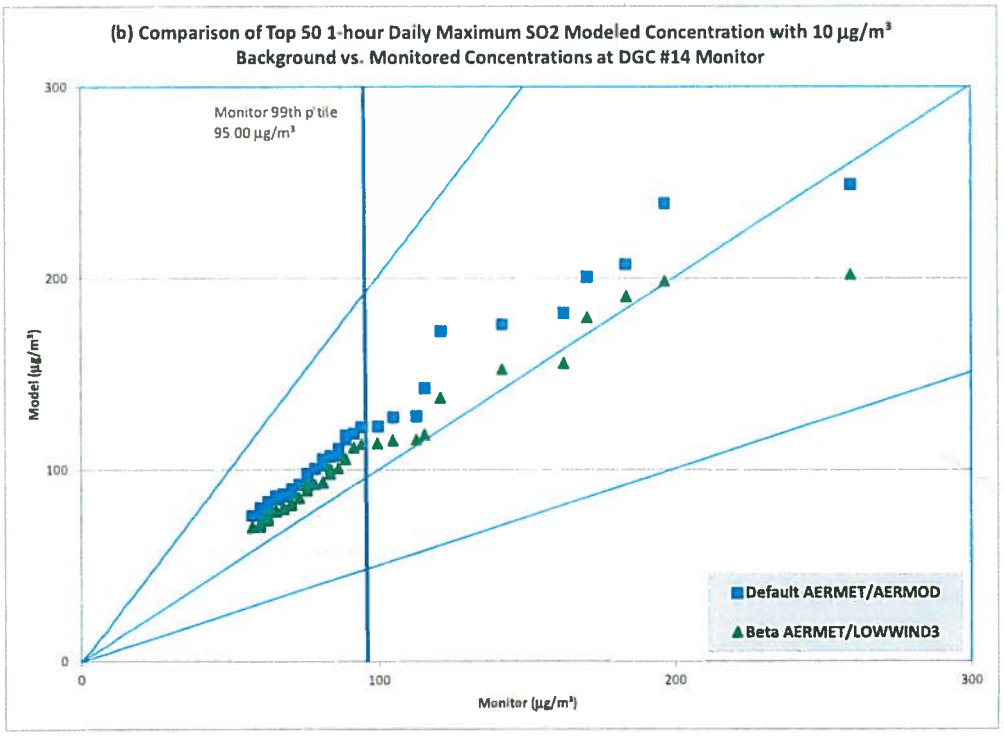
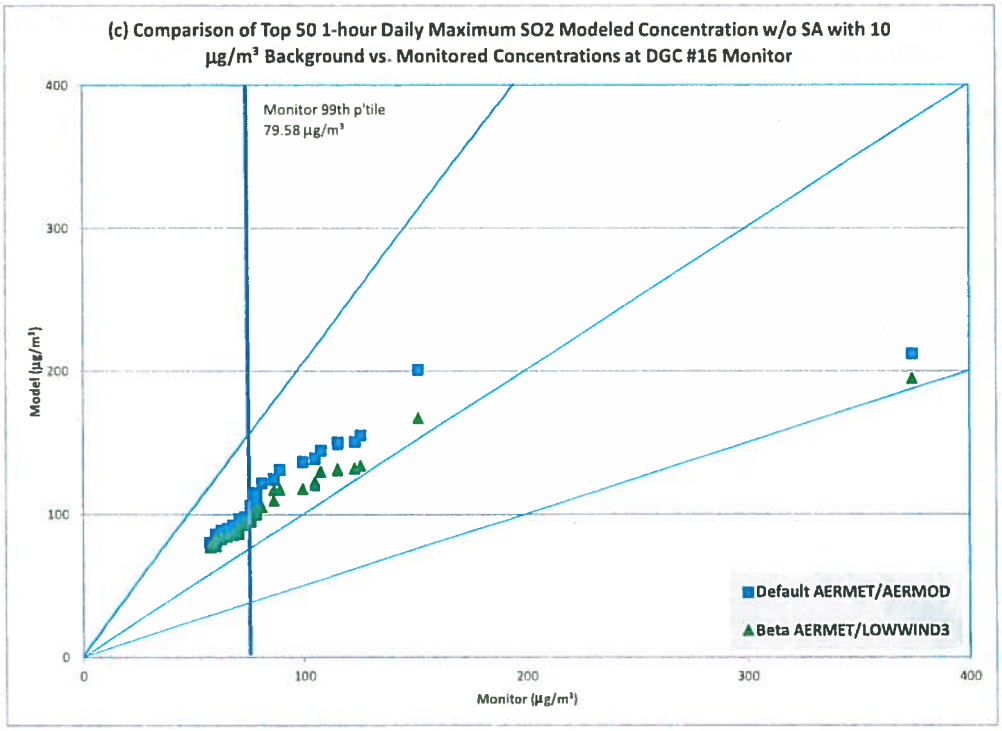
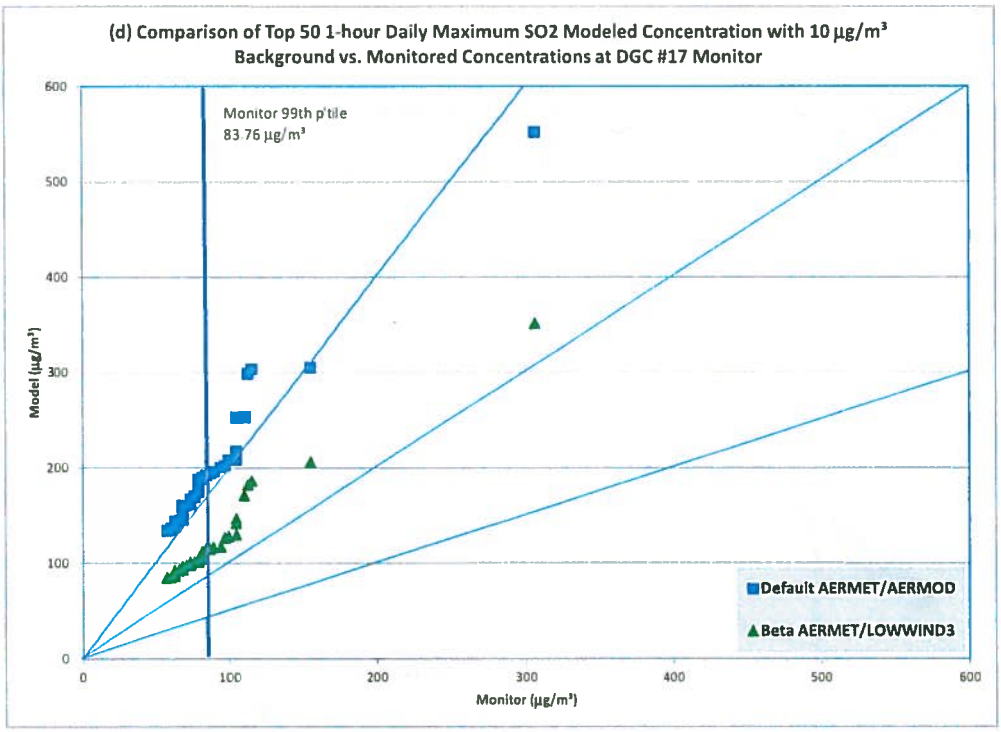


**Figure 2: North Dakota Q-Q Plots: Top 50 Daily Maximum 1-hour $SO_2$ Concentrations. (a) DGC #12 Monitor. (b) DGC#14 Monitor. (c) DGC#16 Monitor. (d) DGC#17 Monitor. (e) Beulah Monitor**




(c) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration w/o SA with 10 µg/m³ Background vs. Monitored Concentrations at DGC #16 Monitor
Monitor 99th p'tile
79.58 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
Default AERMET/AERMOD
Beta AERMET/LOWWIND3


(d) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³ Background vs. Monitored Concentrations at DGC #17 Monitor
Monitor 99th p'tile
83.76 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
600
Default AERMET/AERMOD
Beta AERMET/LOWWIND3

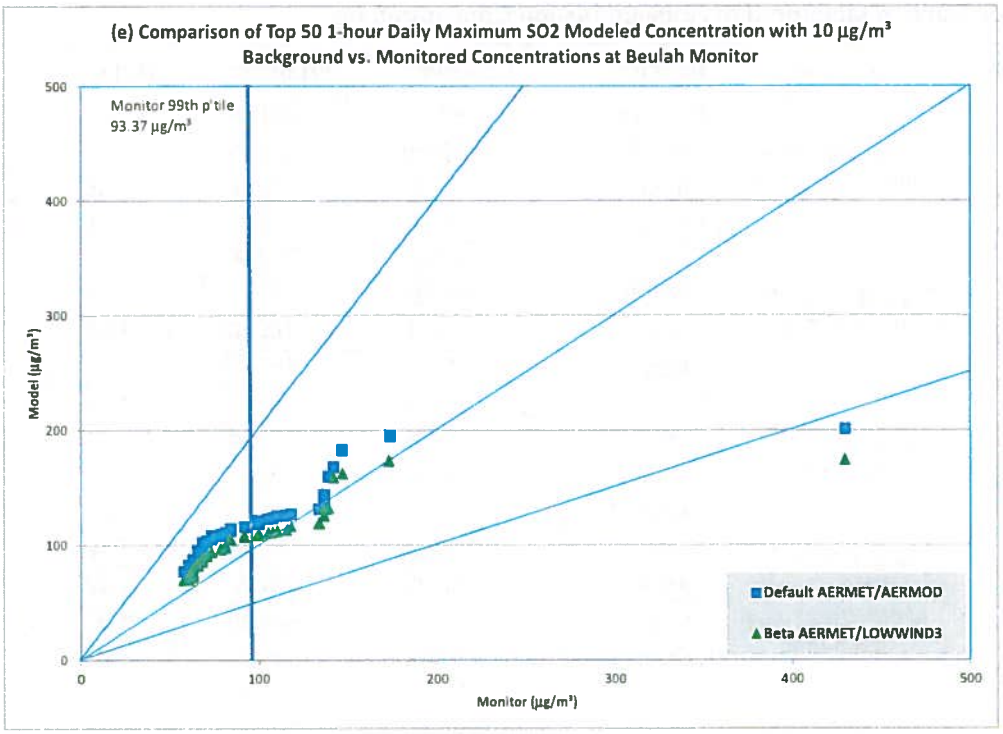

(e) Comparison of Top 50 1-hour Daily Maximum SO2 Modeled Concentration with 10 µg/m³ Background vs. Monitored Concentrations at Beulah Monitor
Monitor 99th p'tile 93.37 µg/m³
Model (µg/m³)
Monitor (µg/m³)
0
100
200
300
400
500
Default AERMET/AERMOD
Beta AERMET/LOWWIND3

**Table 2: Gibson Ratio of Monitored to Modeled Design Concentrations***

| Model Version | Test Case | Monitor | Observed | Predicted | Ratio |
|---|---|---|---|---|---|
| 13350 (previously reported results) | Default AERMET, Default AERMOD | Mt. Carmel | 197.25 | 278.45 | 1.41 |
| | | East Mt. | 206.89 | 230.74 | 1.12 |
| | | Shrodt | 148.16 | 189.63 | 1.28 |
| | | Gibson Tower | 127.12 | 193.71 | 1.52 |
| 15181 | Default AERMET, Default AERMOD | Mt. Carmel | 197.25 | 278.45 | 1.41 |
| | | East Mt. | 206.89 | 230.74 | 1.12 |
| | | Shrodt | 148.16 | 189.63 | 1.28 |
| | | Gibson Tower | 127.12 | 193.71 | 1.52 |
| 13350 (previously reported results) | Beta AERMET, Default AERMOD | Mt. Carmel | 197.25 | 287.16 | 1.46 |
| | | East Mt. | 206.89 | 229.22 | 1.11 |
| | | Shrodt | 148.16 | 189.63 | 1.28 |
| | | Gibson Tower | 127.12 | 193.71 | 1.52 |
| 13350 (previously reported results) | Beta AERMET, AERMOD with LOWWIND2 $\sigma_v$ = 0.3 m/sec | Mt. Carmel | 197.25 | 280.32 | 1.42 |
| | | East Mt. | 206.89 | 224.65 | 1.09 |
| | | Shrodt | 148.16 | 184.82 | 1.25 |
| | | Gibson Tower | 127.12 | 192.22 | 1.51 |
| 13350 (previously reported results) | Beta AERMET, AERMOD with LOWWIND2 $\sigma_v$ = 0.5 m/sec | Mt. Carmel | 197.25 | 277.57 | 1.41 |
| | | East Mt. | 206.89 | 224.65 | 1.09 |
| | | Shrodt | 148.16 | 176.81 | 1.19 |
| | | Gibson Tower | 127.12 | 192.22 | 1.51 |
| 15181 | Beta AERMET, AERMOD with LOWWIND3 | Mt. Carmel | 197.25 | 276.12 | 1.40 |
| | | East Mt. | 206.89 | 217.05 | 1.05 |
| | | Shrodt | 148.16 | 175.42 | 1.18 |
| | | Gibson Tower | 127.12 | 175.92 | 1.38 |
| 13350 (previously reported results) | SHARP | Mt. Carmel | 197.25 | 225.05 | 1.14 |
| | | East Mt. | 206.89 | 202.82 | 0.98 |
| | | Shrodt | 148.16 | 136.41 | 0.92 |
| | | Gibson Tower | 127.12 | 148.64 | 1.17 |

*Design Concentration: 99$^{th}$ percentile peak daily 1-hour maximum, averaged over the years modeled and monitored.

**Figure 3: Gibson Ratio of Monitored to Modeled Design Concentration Values**

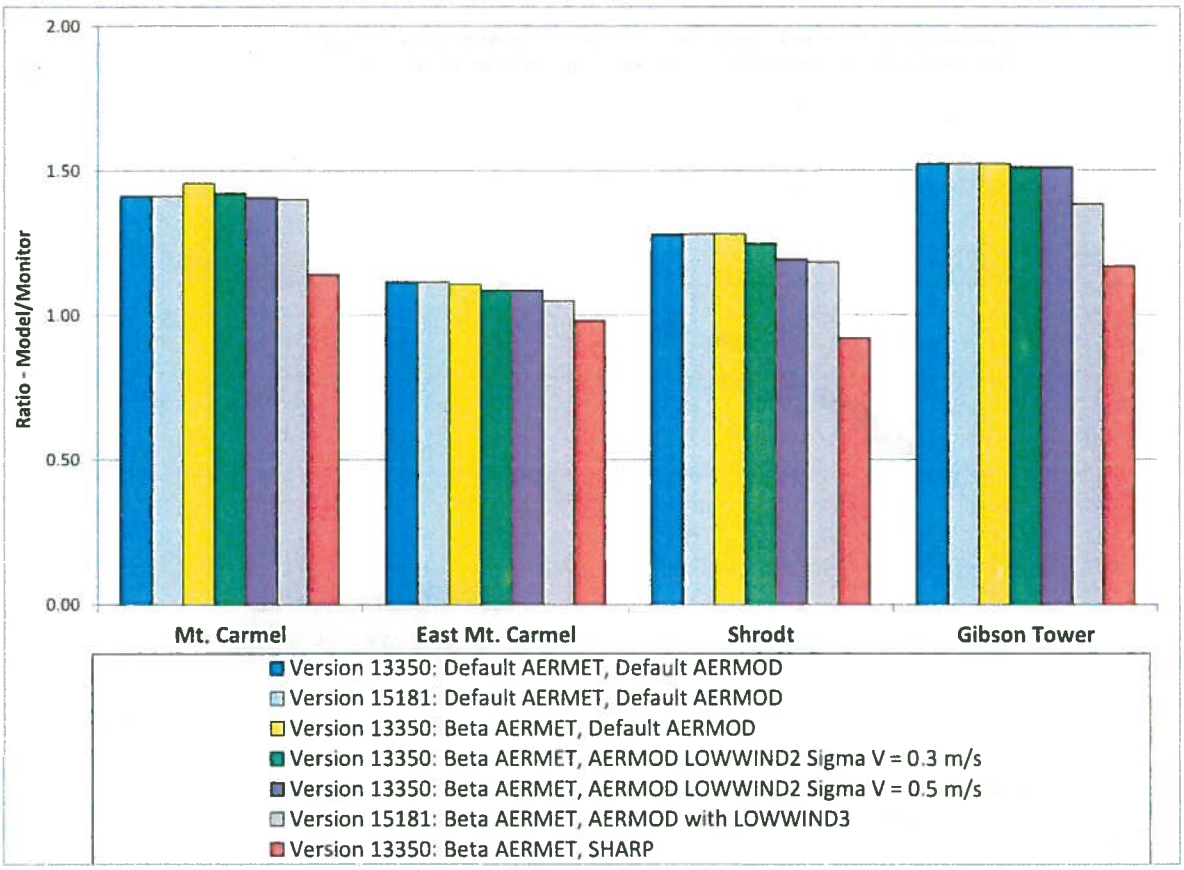
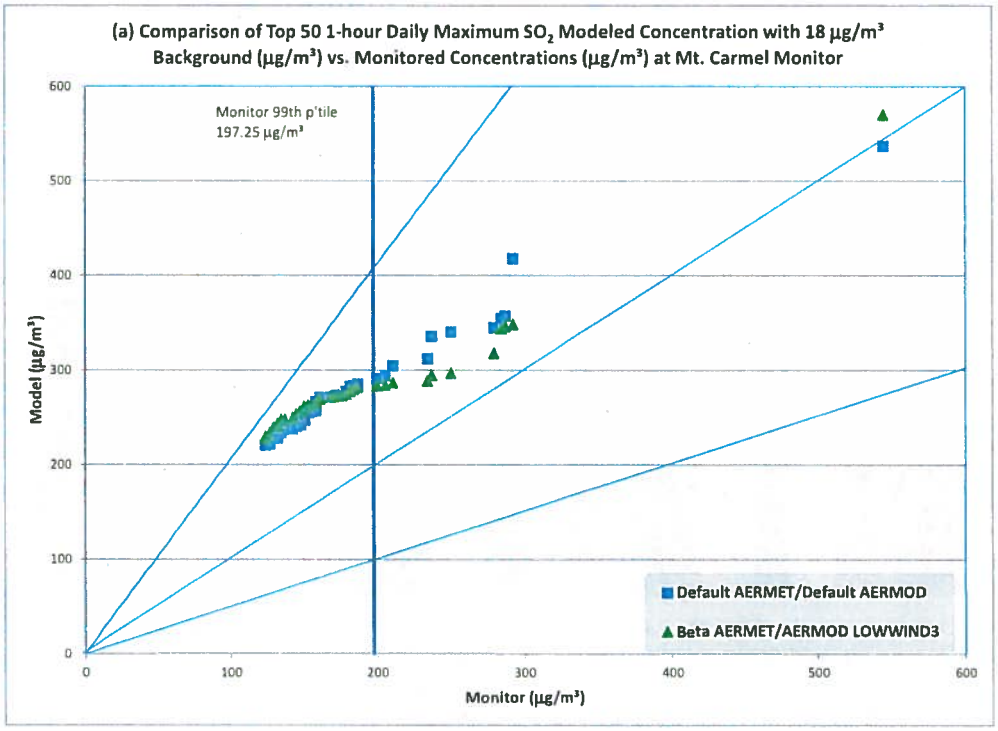
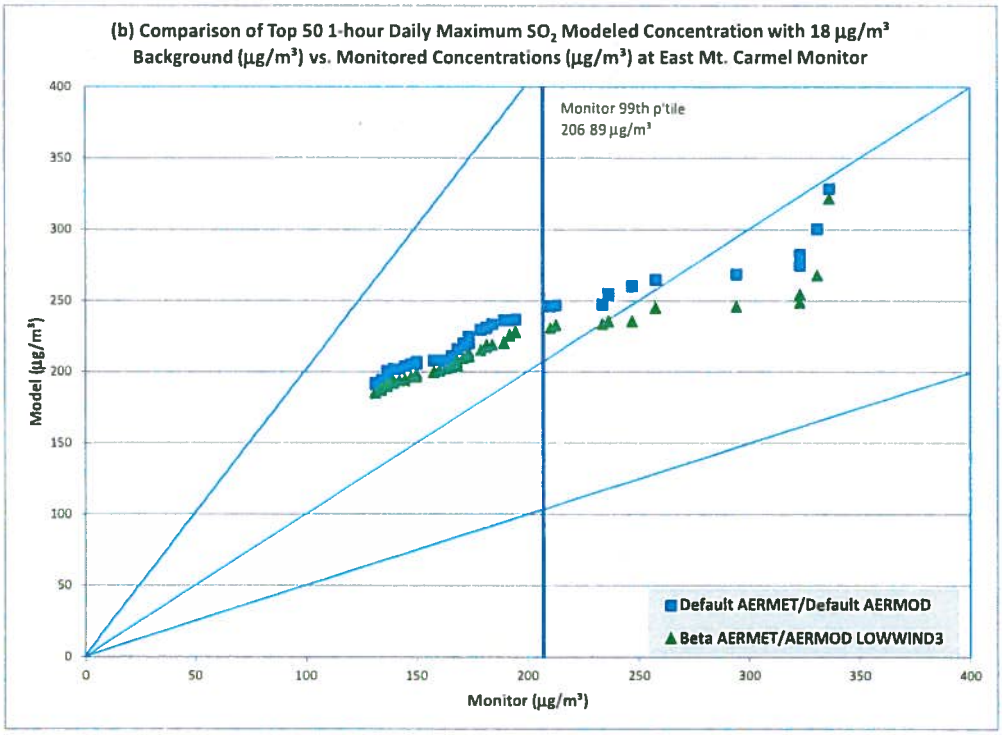
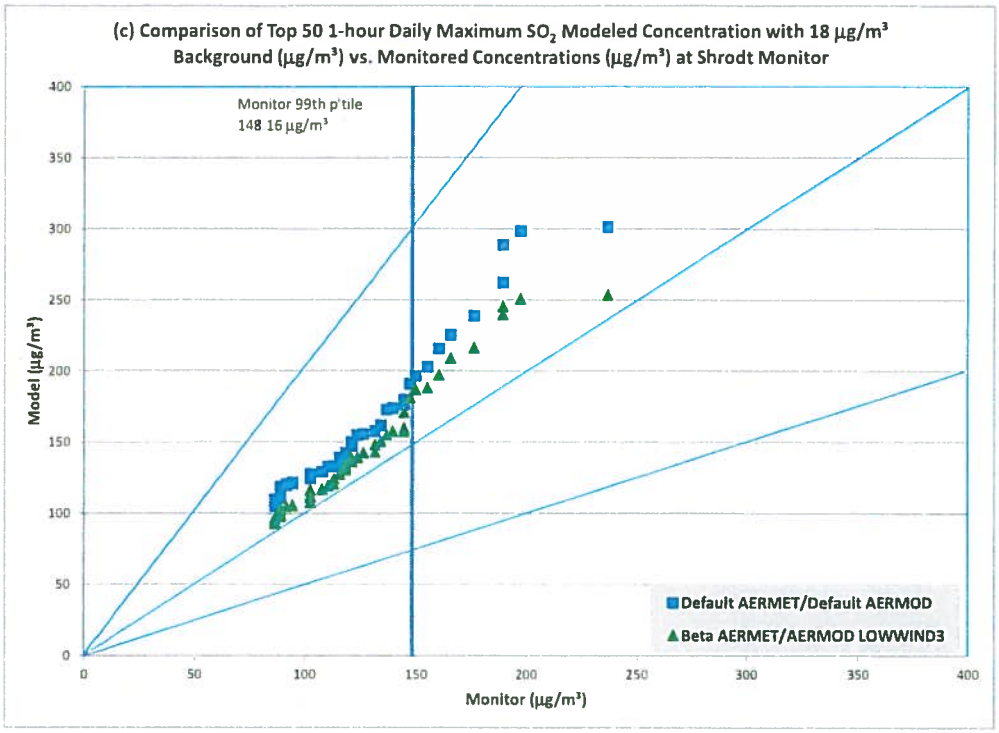
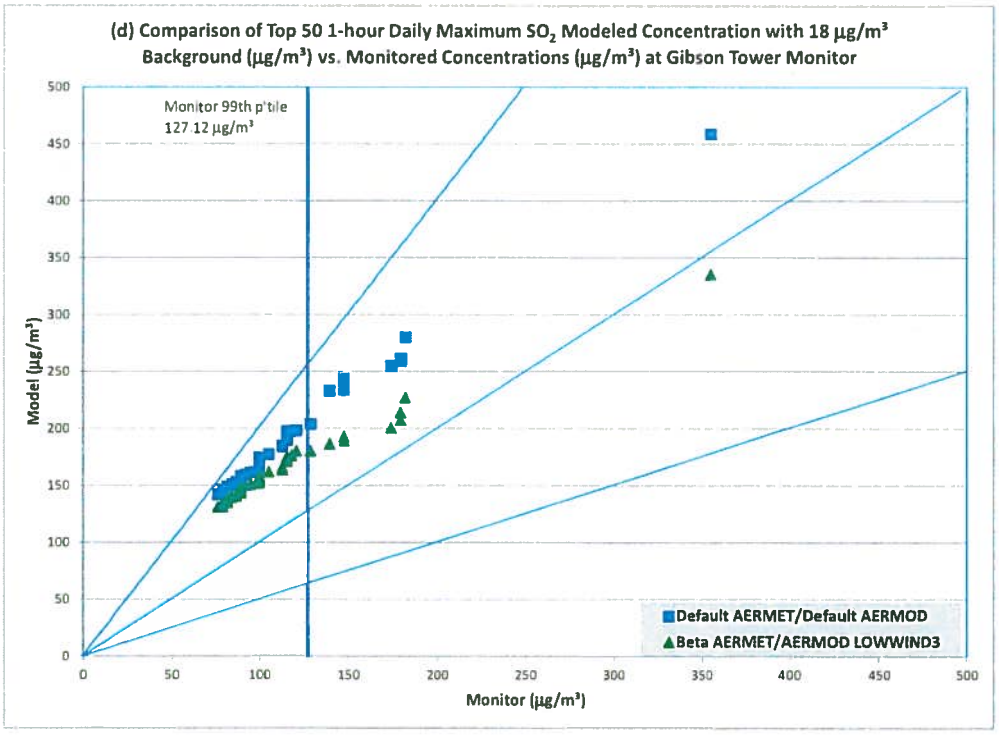


**Figure 4: Gibson Q-Q Plots: Top 50 Daily Maximum 1-hour $SO_2$ Concentrations.**
**(a) Mt. Carmel Monitor. (b) East Mt. Carmel Monitor. (c) Shrodt Monitor. (d) Gibson Tower Monitor**




(c) Comparison of Top 50 1-hour Daily Maximum $SO_2$ Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Shrodt Monitor
Monitor 99th p'tile
148 16 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3


(d) Comparison of Top 50 1-hour Daily Maximum $SO_2$ Modeled Concentration with 18 µg/m³ Background (µg/m³) vs. Monitored Concentrations (µg/m³) at Gibson Tower Monitor
Monitor 99th p'tile
127 12 µg/m³
Model (µg/m³)
Monitor (µg/m³)
Default AERMET/Default AERMOD
Beta AERMET/AERMOD LOWWIND3